Protecting infrastructures from natural and anthropogenic hazards

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Overview

- 40 years of SAR missions…
- Multitemporal Synthetic Aperture Radar Interferometry (MT-InSAR) : pros & cos
- Natural vs Anthropogenic phenomena
- Case studies
- Conclusions
- The way forward

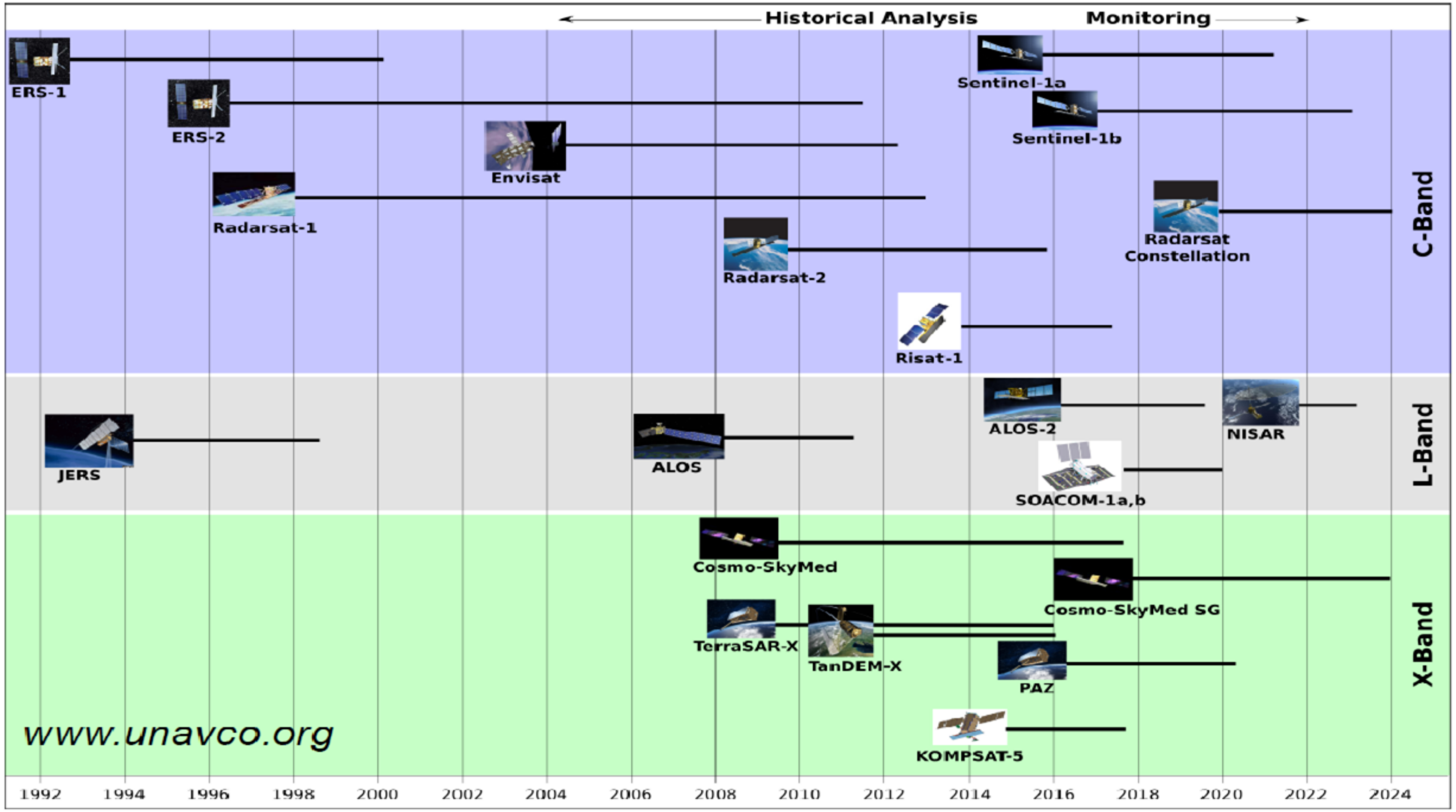
About 40 years of SAR missions…

- The history of civilian satellite SAR systems began with the 1978 NASA Seasat satellite, which was the first satellite equipped with a SAR sensor, operating at L band (24 cm of wavelength) of the electromagnetic spectrum.

- The mission was designed for remote sensing of the Earth's oceans to demonstrate the feasibility of global satellite monitoring of oceanographic phenomena and to help determine the requirements for an operational ocean remote sensing satellite system

About 40 years of SAR missions…

- Improved performances (e.g. spatial resolution, even sub-metric)
- Multi-frequency (X- C- L-band)
- higher revisit time (from 35 days to 1-2 days) thanks constellations
- different viewing angles (from 23° fixed of ERS to 19°- 50° of CSK)
- Polarimetry
- Multi-mode: different acquisition mode capabilities



Multi-temporal InSAR

How can we exploit the large dataset of SAR images available today?

A number of advanced InSAR techniques have been developed since 20 years ago:

- PS and SqueeSAR from POLIMI
- SBAS from CNR-IREA
- IPTA from GAMMA Remote Sensing
- PSP from E-GEOS
- STAMPS from Stanford University
- ….and many others

These are usually known as *Multi Temporal InSAR techniques*

MT-InSAR : Pros & Cos

- Using a huge number of SAR data provide a spatially dense (each interferogram) and temporally dense (time series) information.
- Detection of atmospheric artifacts spatially correlated and temporally uncorrelated.
- More accurate estimation and subsequent removal of orbital ramp and/or topographic residuals.
- Measure velocity and displacement with high accuracy (up to 1 mm/yr).
- Possibility to work in low or high resolution.
- Expensive computational time for the processing.
- Wide storage space needed on hard-disk (not true for all the techniques).
- Needed tuning of a large number of parameters during the processing.
- Needed of at least 20-25 SAR images to obtain reliable results.

Multi-temporal InSAR

MT-InSAR techniques allow to analyse the different components of the interferometric phase, with high accuracy and reliability.

With MT-InSAR we can:

- ❑ estimate and removal of the phase contribution of the atmosphere (the wet-atmo delay)
- ❑ estimate the topography, i.e. elevation information, for better motion modelling and precise geocoding
- ❑ model the phase displacement to evaluate spatial and temporal characteristics of ground movements

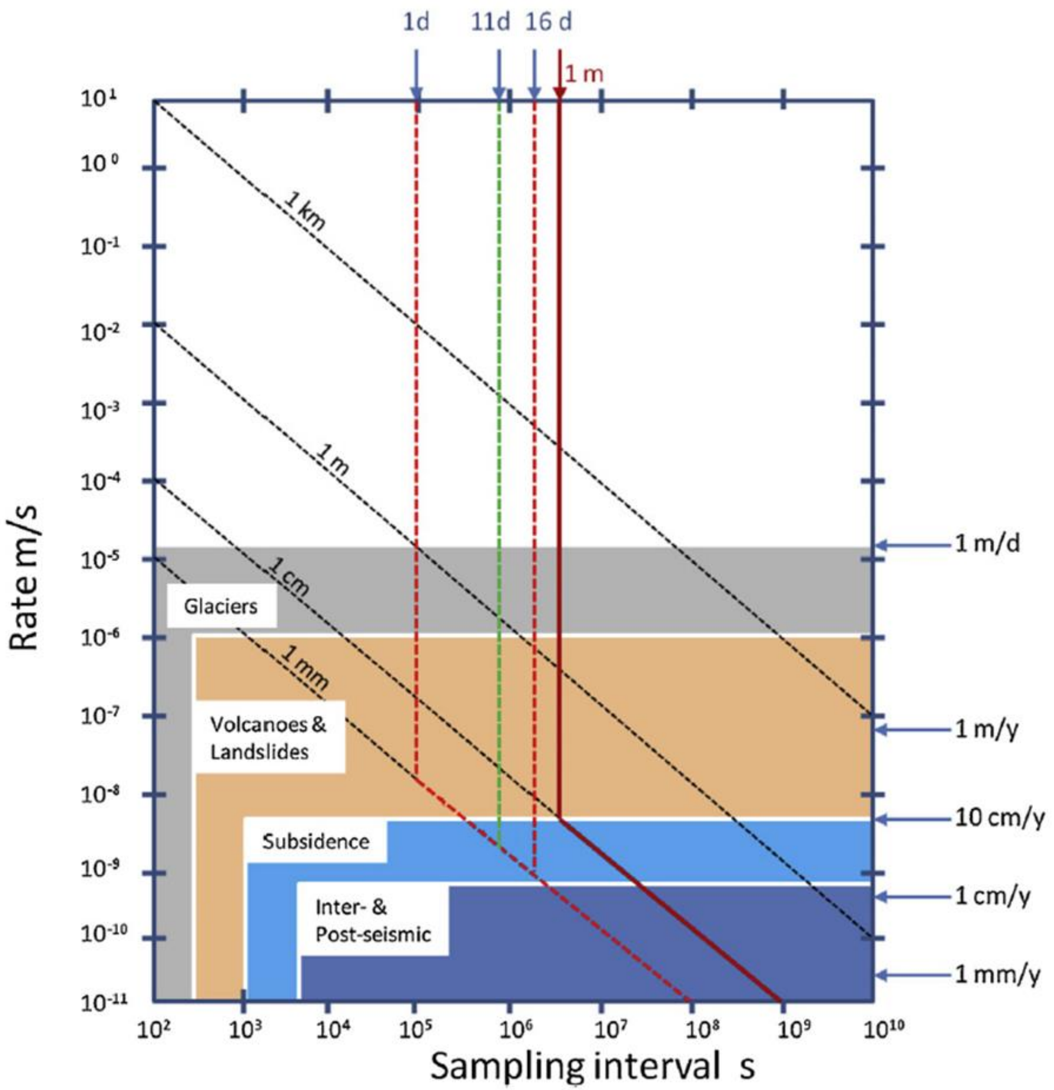
MT-InSAR : Pros & Cos

 or  ?

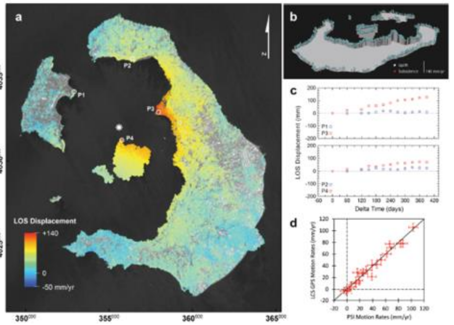
Different natural phenomena deal with:
- different spatial scales
- different time span
- different velocity rates

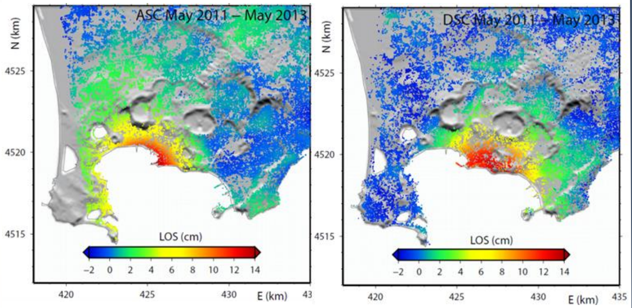
Consequently the strategies for monitoring may differ in terms of:

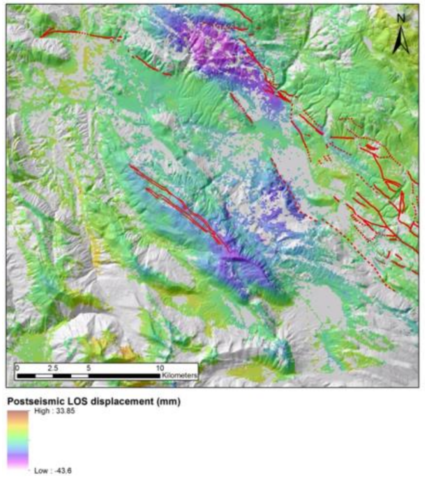
- satellite mission and/or acquisition mode (wavelength and spatial coverage)
- revisit time interval (1d, 4d, 12d)
- temporal sampling interval (number of images)

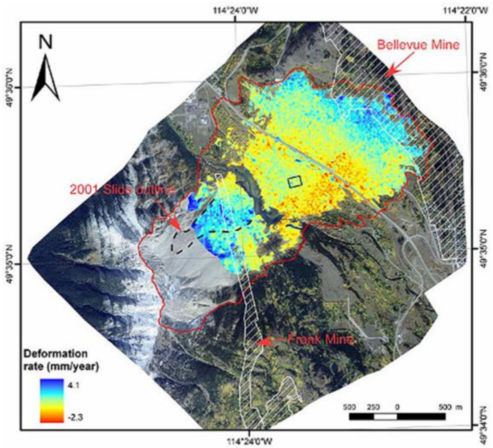


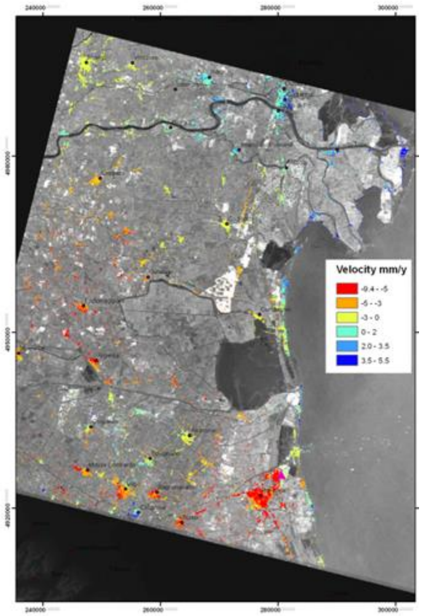
Natural vs Anthropogenic phenomena

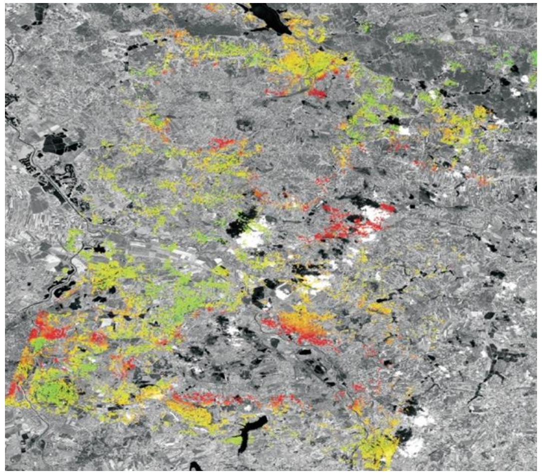






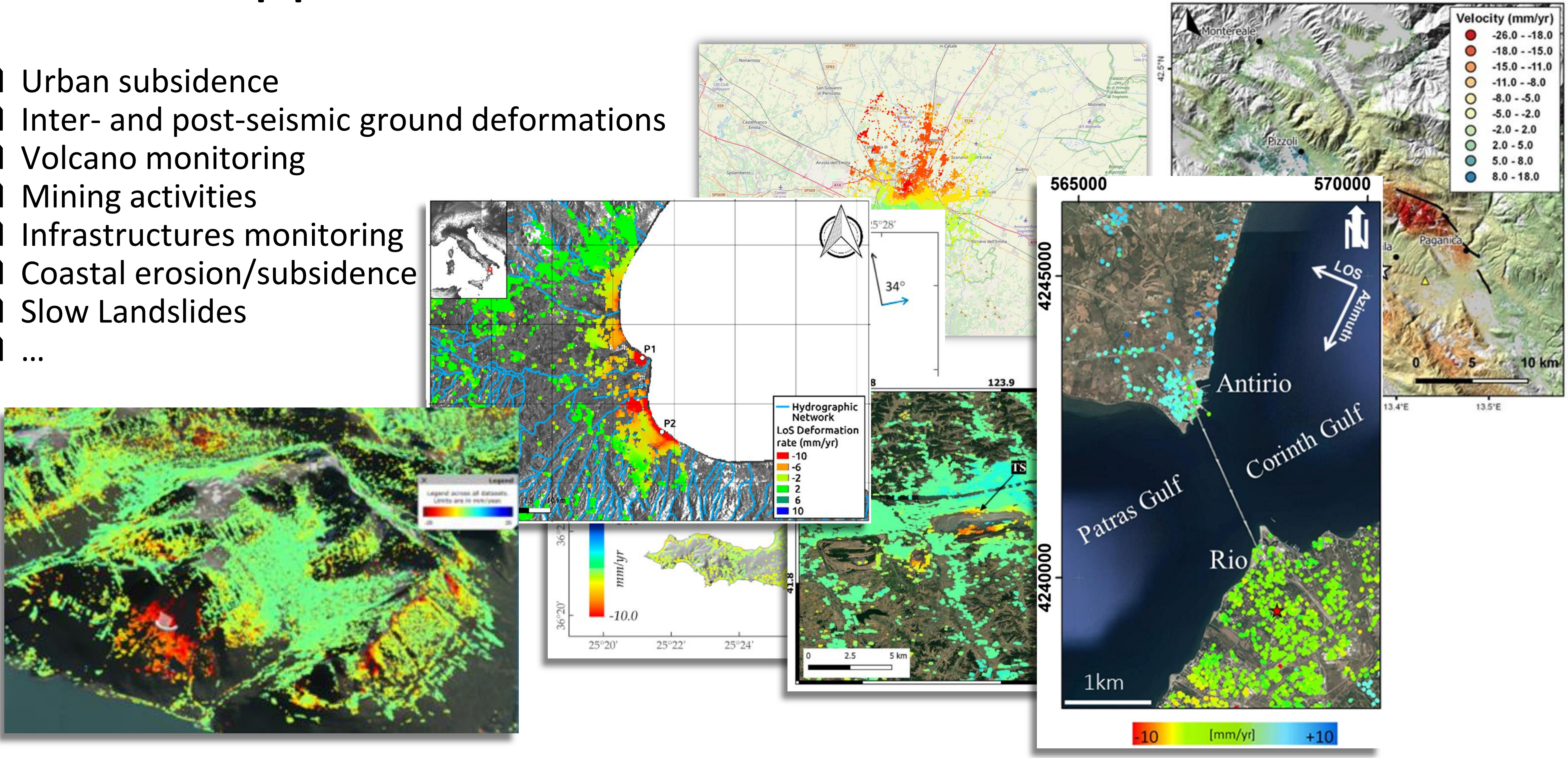






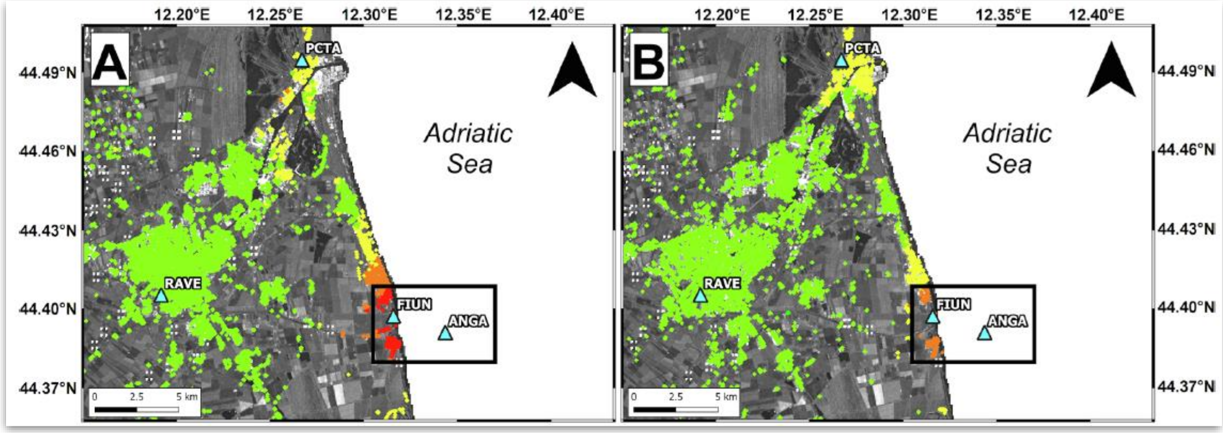
MT-InSAR applications

- Urban subsidence
- Inter- and post-seismic ground deformations
- Volcano monitoring
- Mining activities
- Infrastructures monitoring
- Coastal erosion/subsidence
- Slow Landslides
- …

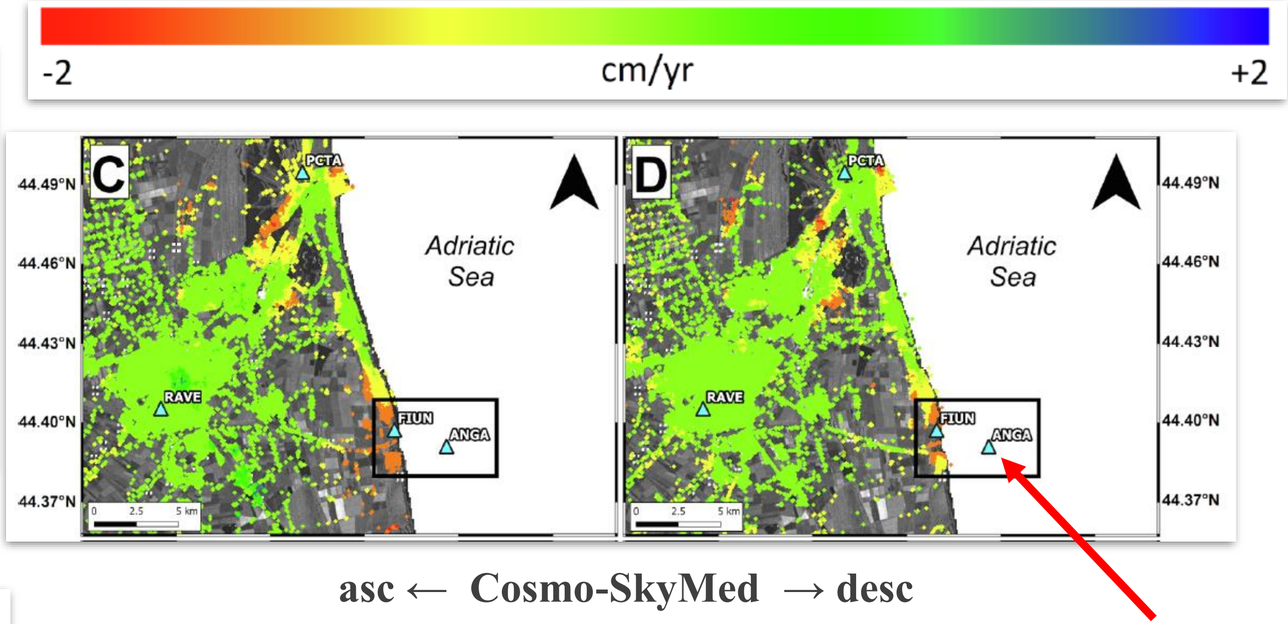


Case Studies …

Onshore and offshore subsidence in Adriatic Sea coast

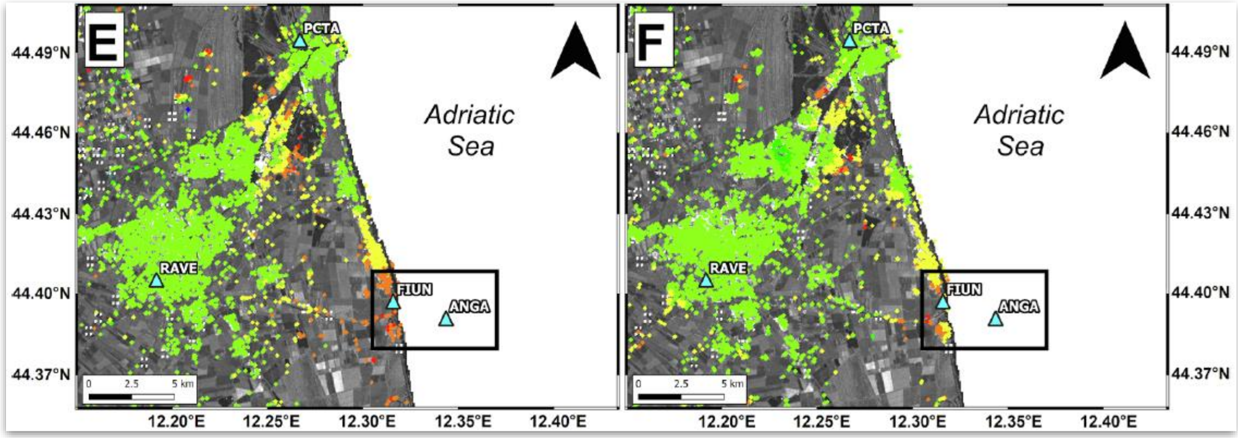


asc ← Envisat → desc



asc ← Cosmo-SkyMed → desc

offshore platform (gas)



asc ← Sentinel-1 → desc

- ★ almost 20 years: Envisat+S1+CosmoSkymed from Dec. 2002 to July 2018
- ★ clear deformation pattern located along the coastline in the proximity of Lido di Dante and Fiumi Uniti villages: rates up to about -2 cm/yr
- ★ deformation rates decrease over time from 2003 to 2018 and to less than -1 cm/yr

Onshore and offshore subsidence in Adriatic Sea coast

InSAR and GNSS comparison

- ★ ***RAVE*** station is the reference point for both GPS and SAR
- ★ GPS projected into SAR LoS

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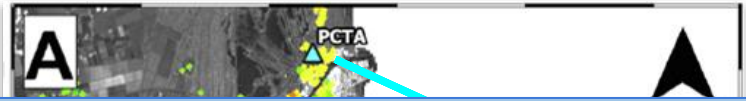
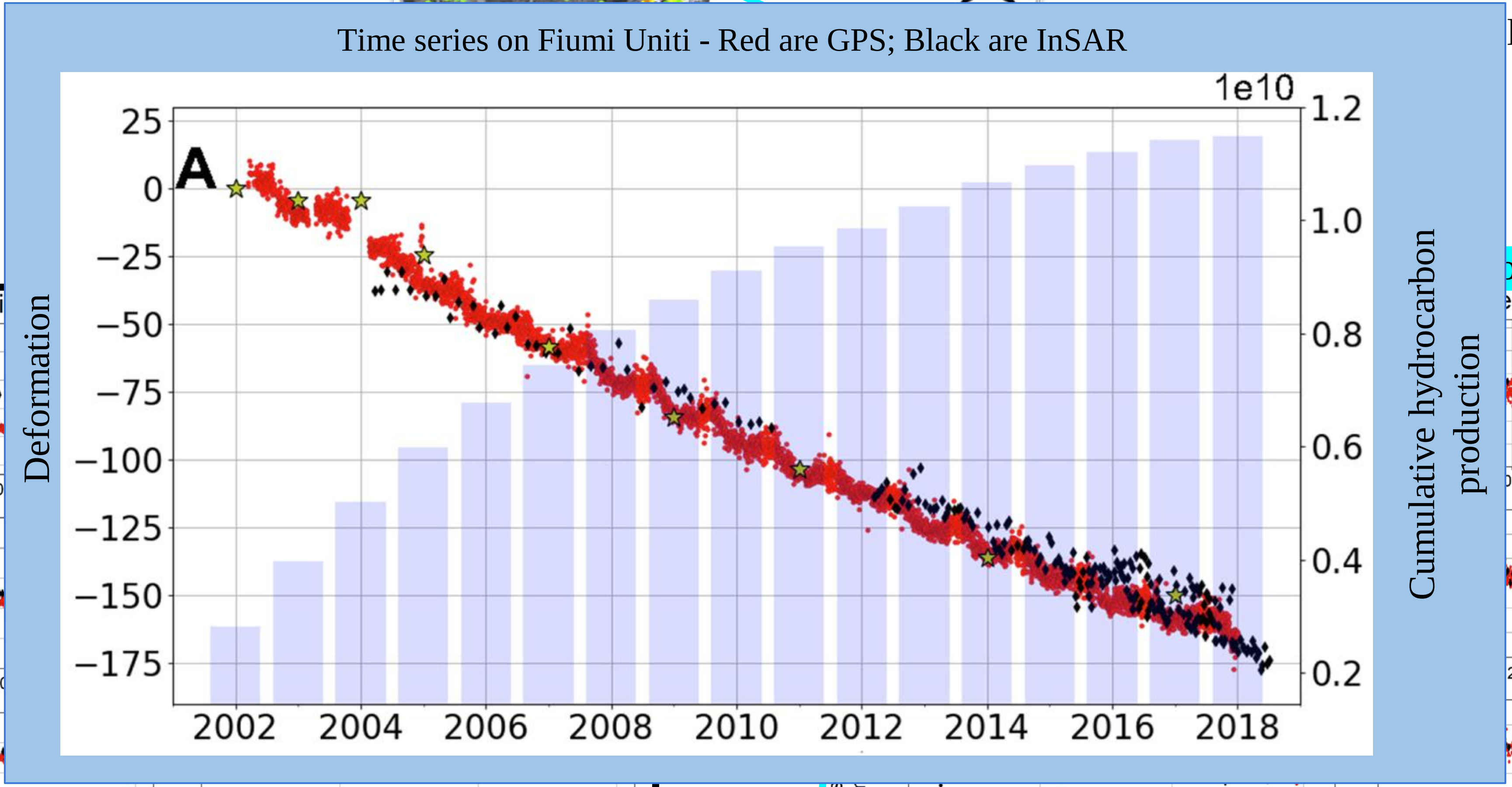
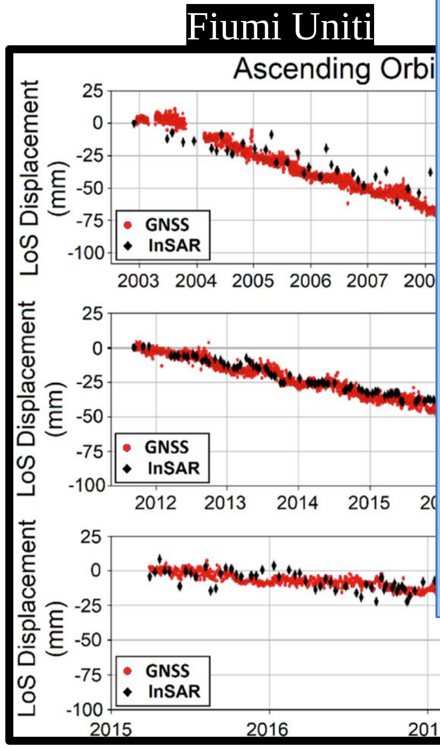
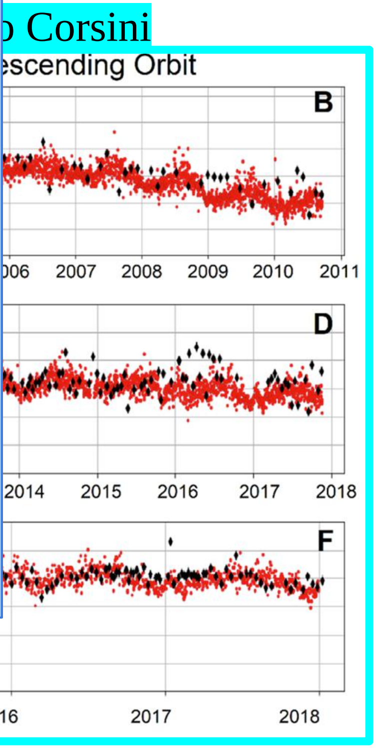
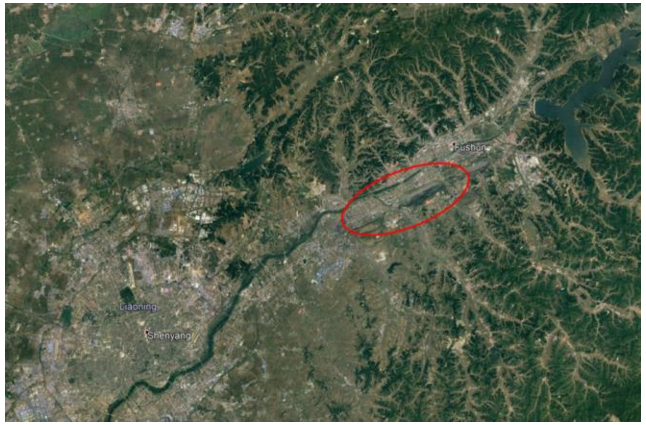




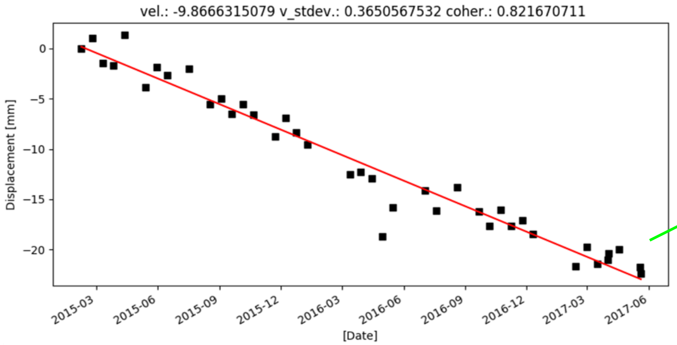


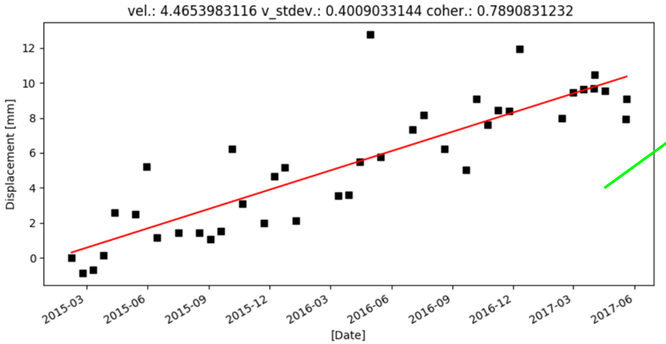


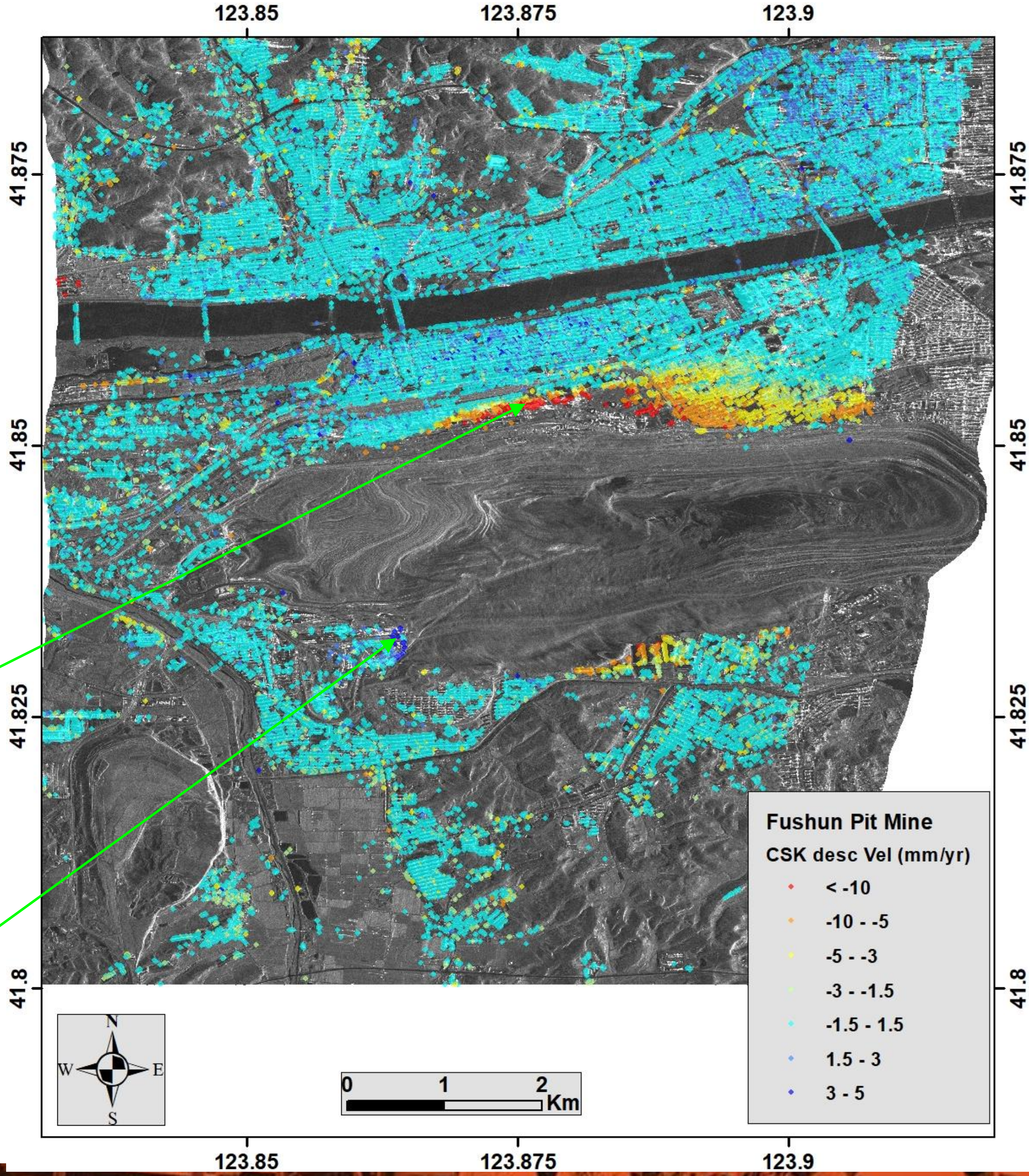
Monitoring open mine: the *‘Fushun’* open pit mine case (Northeastern China)



- ★ 40 COSMO-SkyMed data
- ★ Descending orbit
- ★ Incidence angle: 23.9°
- ★ Time span: 7/2/2015-20/5/2017
- ★ PS technique

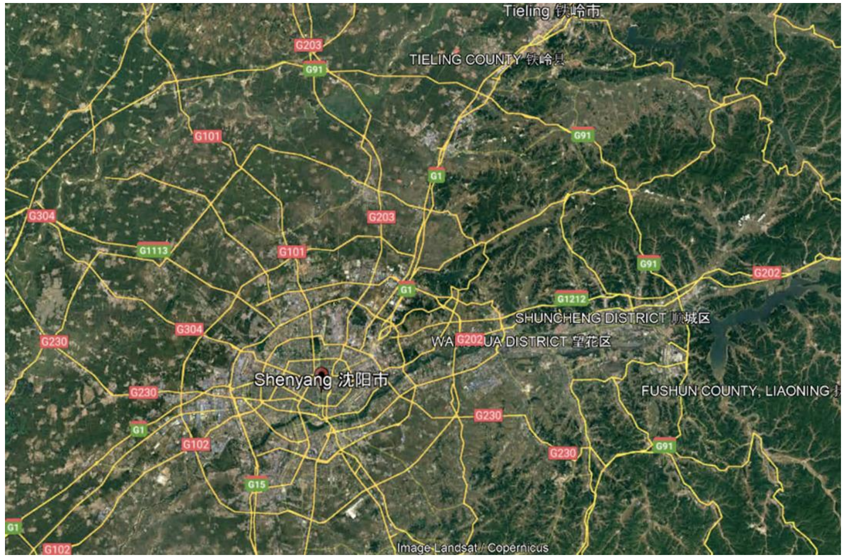




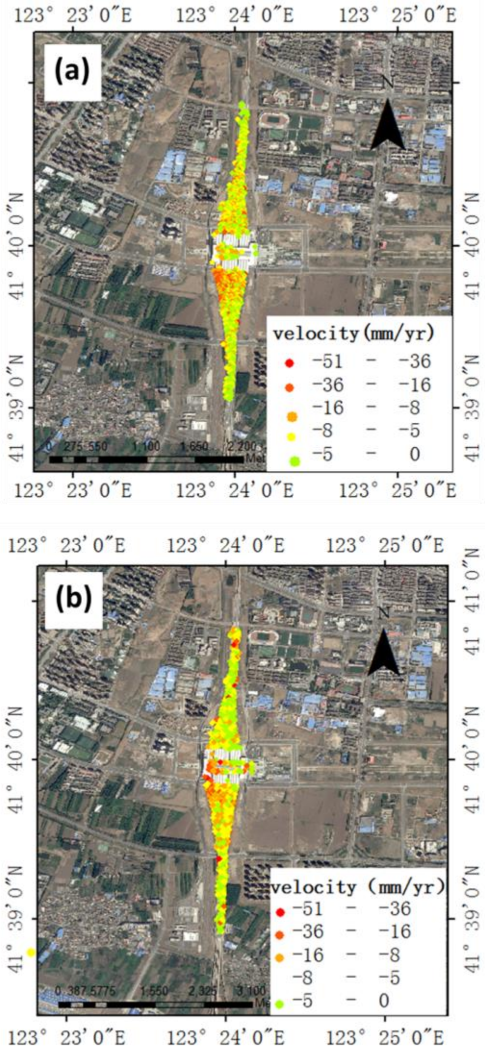


(Courtesy ESA-MOST DRAGON-4 project)

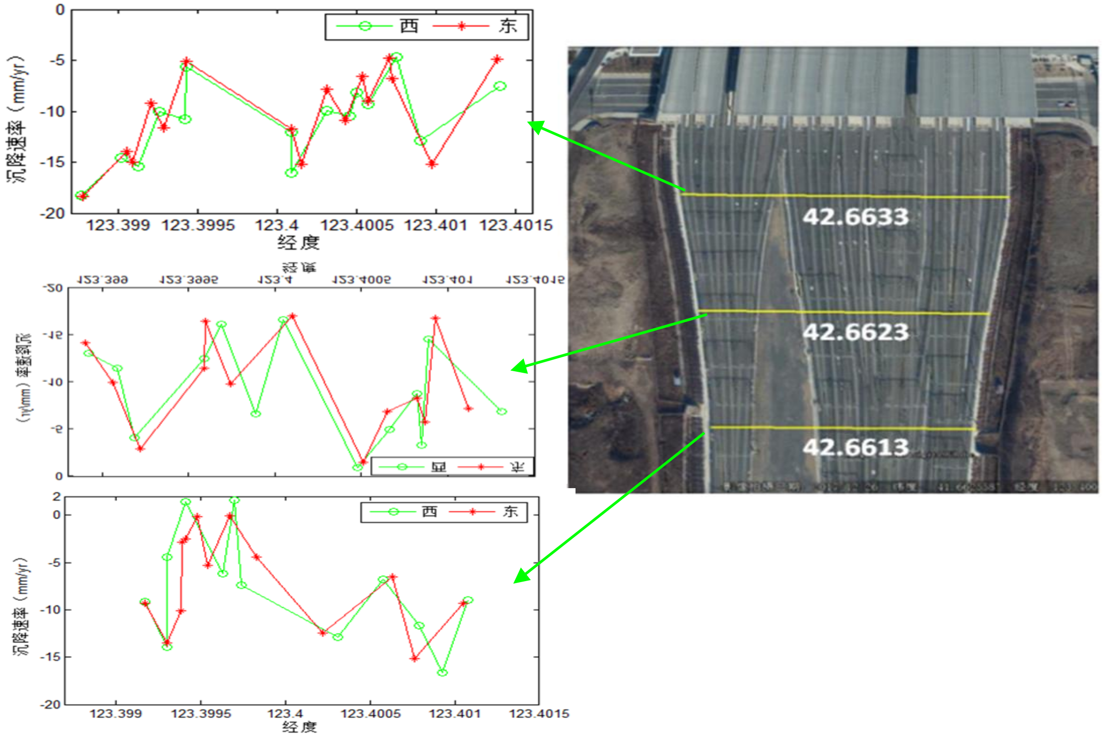
Monitoring infrastructures: the Shenyang Railway Station case (Northeastern China)



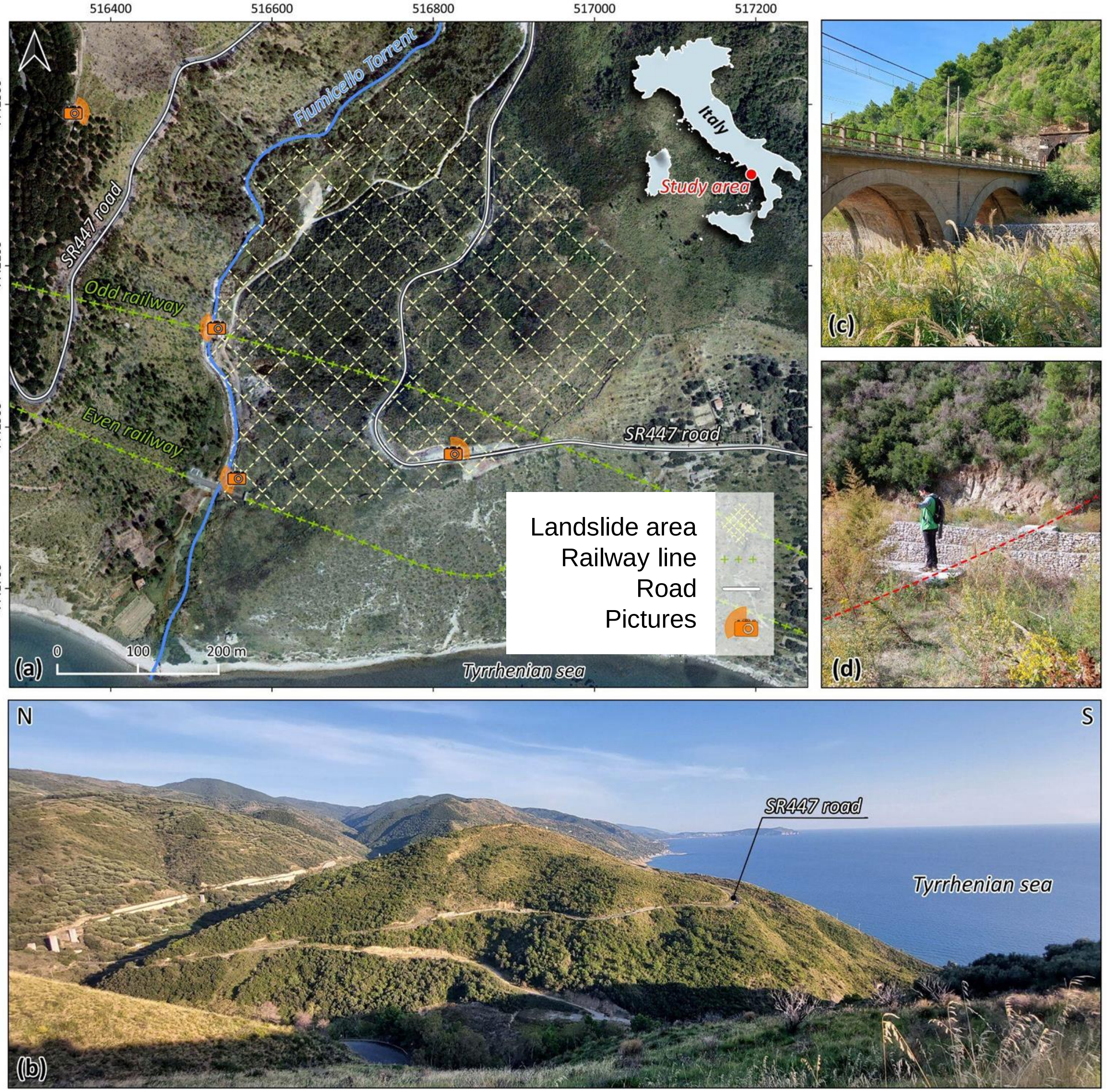
(Courtesy ESA-MOST DRAGON-4 project)



We used CSK data to monitor the ground movements occurred close to the newly-built Shenyang South railway station and the nearby high-speed railway tracks). 18 X-band SAR images acquired from two different adjacent orbits, overlapping on the Shenyang South railway station, were used. The largest deformation happens on the rail tracks near the southern part of the platform, with velocities varying between -50 and -15 mm/yr. Ground motions in other parts of the station are smaller, with deformation rates varying from -15 mm/yr to 0.

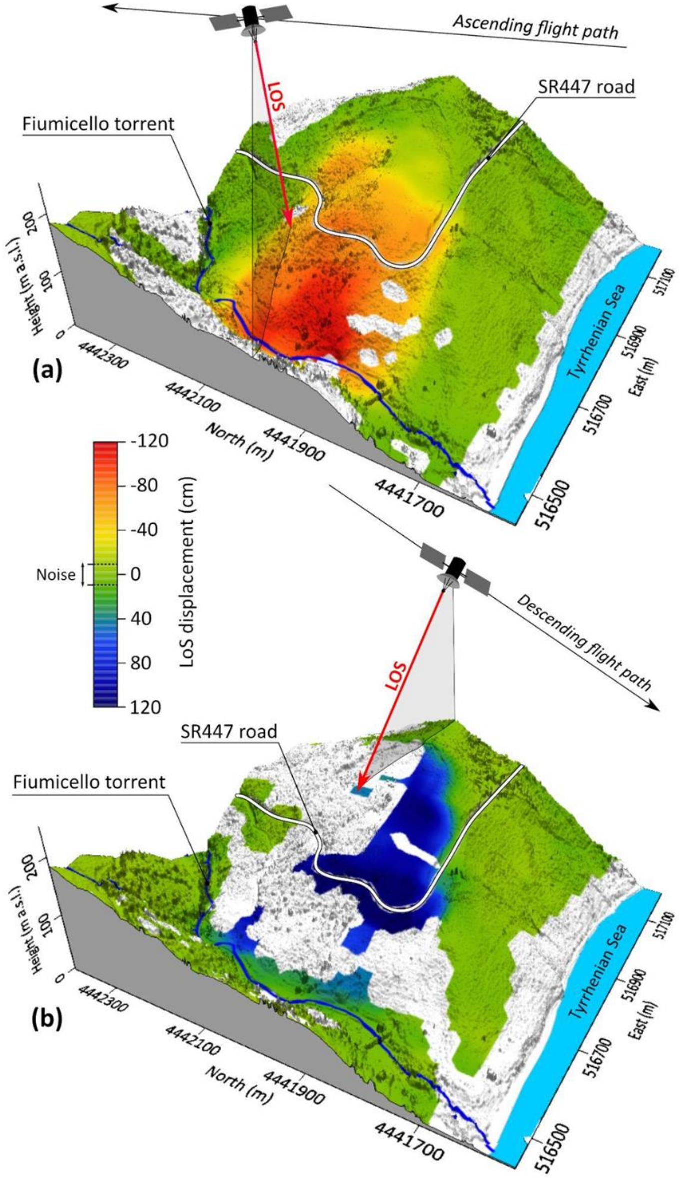


Monitoring landslide displacements: the 'Pisciotta' landslide case study (southern Italy)



The landslide extends approximately 0.2 km^2 and moves at a rate of about 100 cm/y towards the Fiumicello riverbed.The landslide movements affect the SR447 road and the national railway. Currently, the assessment of the present-day activity and kinematics of the Pisciotta landslide has not been provided yet.

Sentinel-1 LoS displacements in the period October 2016-October 2021 highlight movements up to 130 cm



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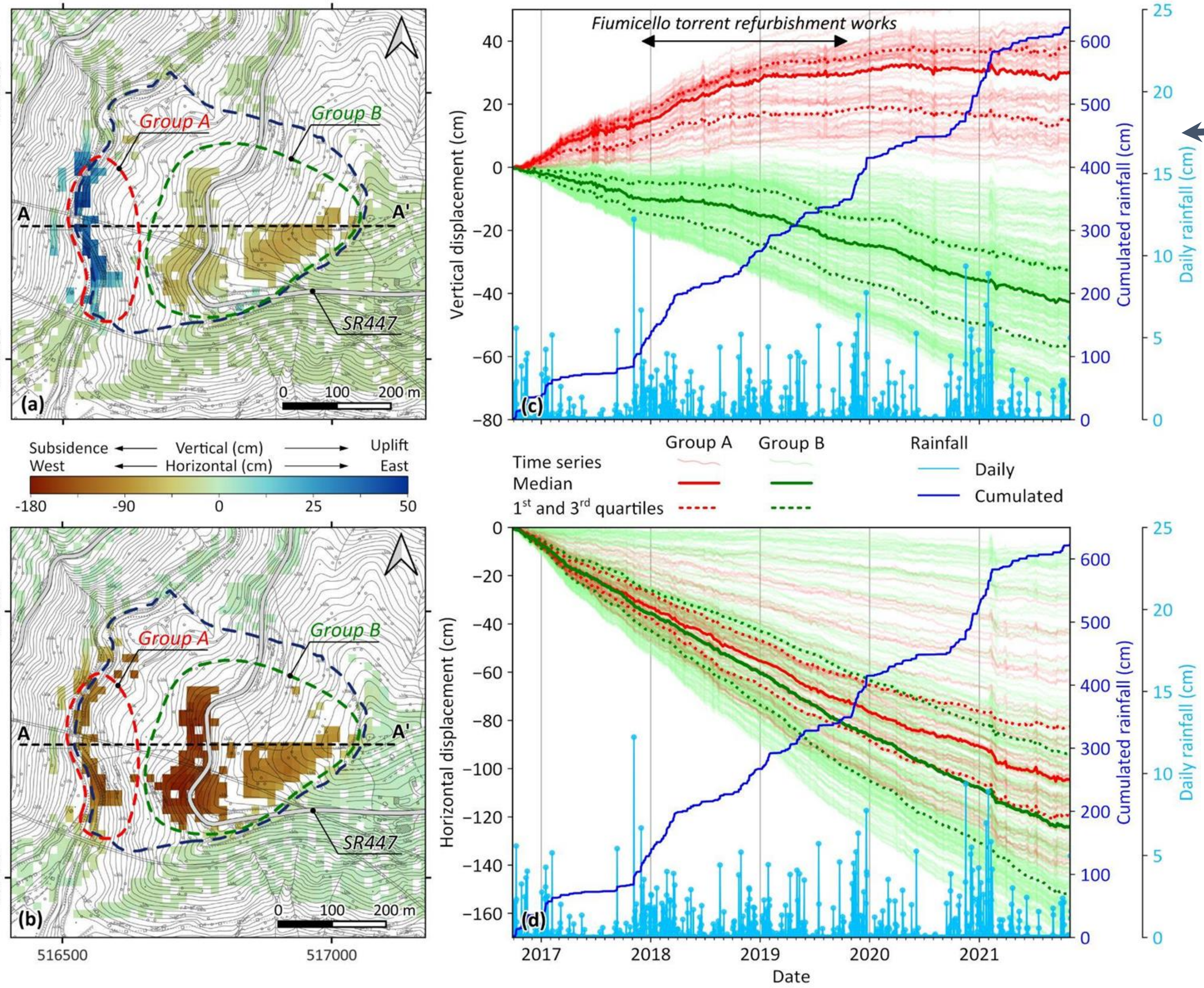
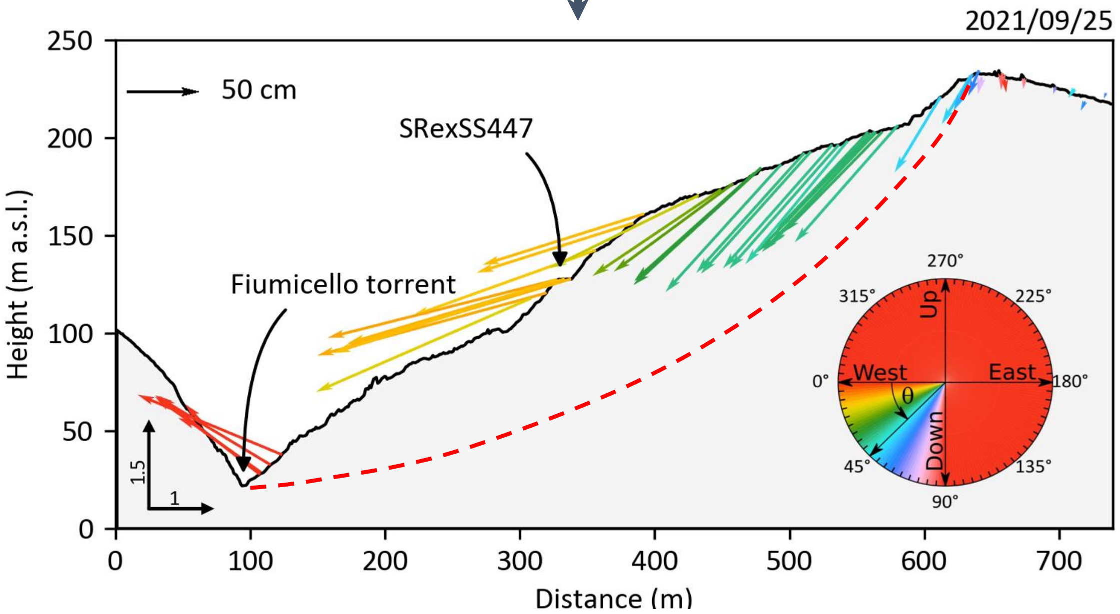


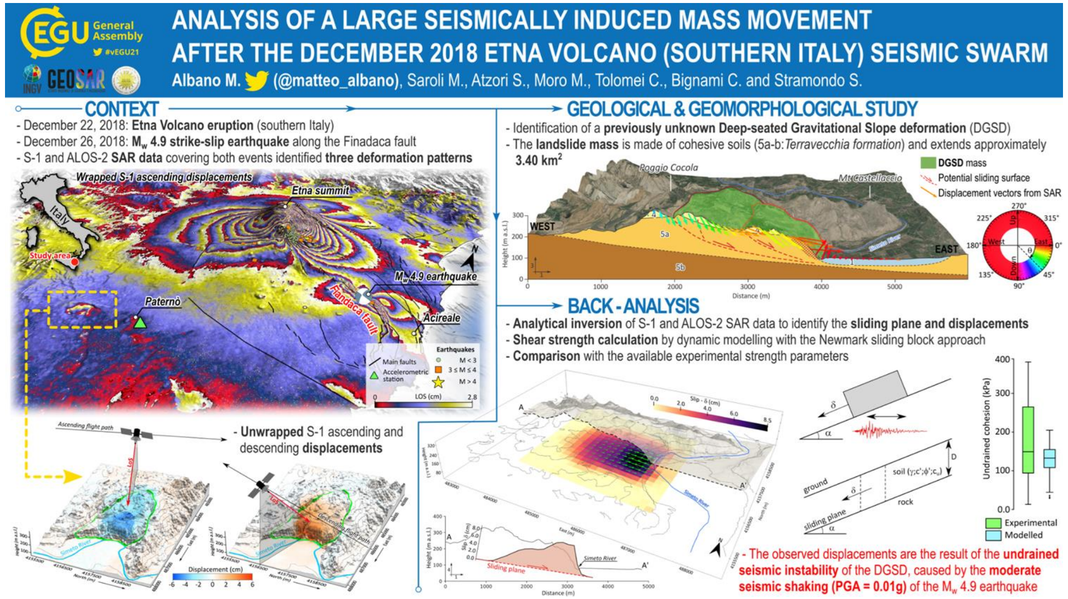
Displacement decomposition in vertical (a and c) and East-West (b and d) components highlights that the landslide subsides in its upper part (group B) and uplifts at its toe (group A), while moves westward with a decreasing rate over time.

Cumulative displacement vectors along the A-A' cross-section highlight that the landslide kinematics is compatible with a deep sliding surface (dashed red curve).



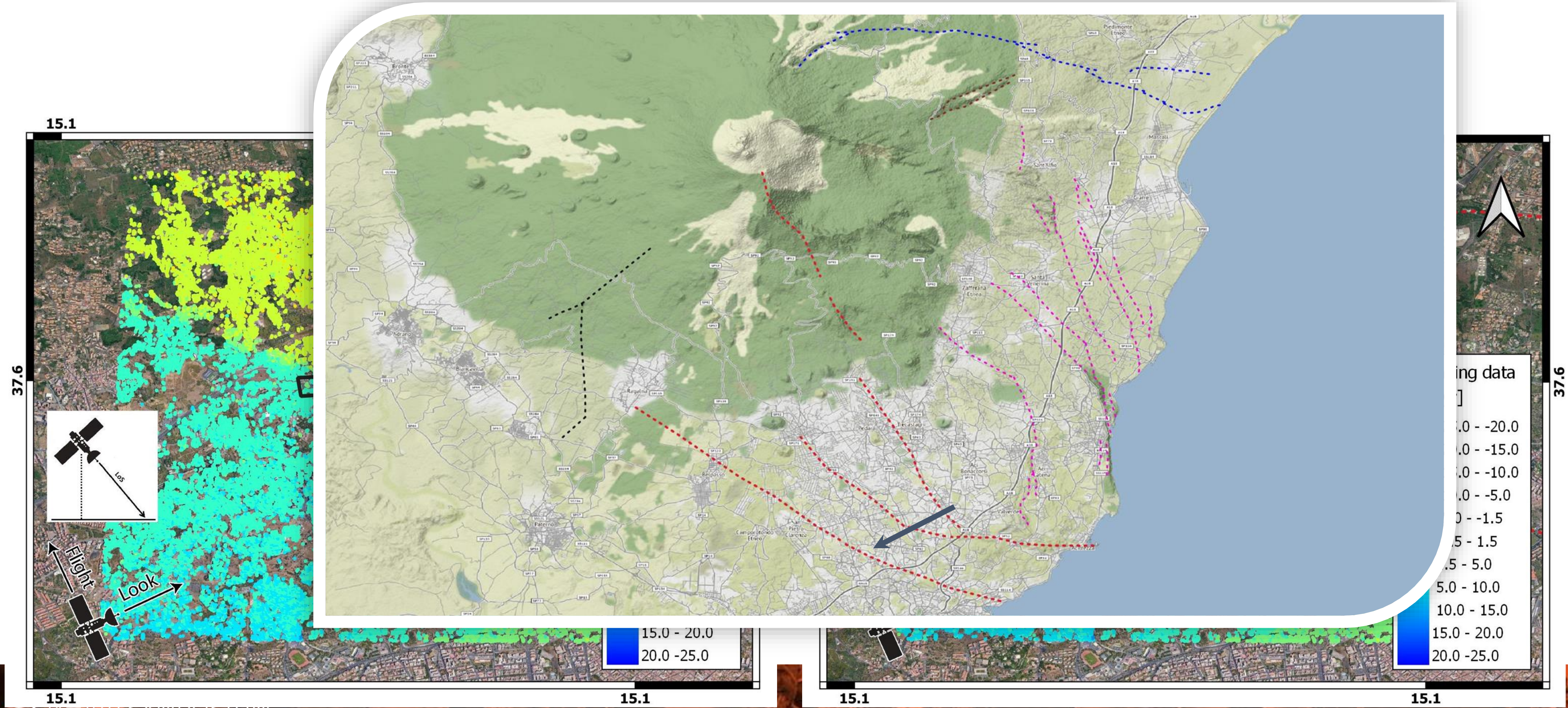
Viaduct S.Paolo in Catania

Volcano-tectonic hazards on the Etna Volcano flank



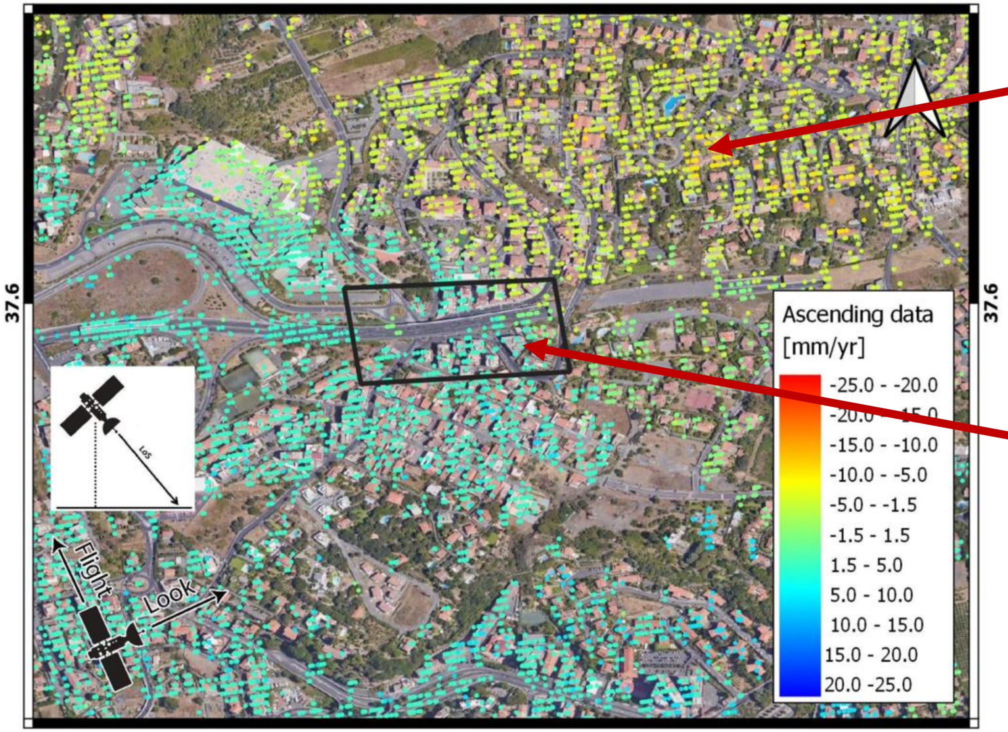
Viaduct S.Paolo in Catania

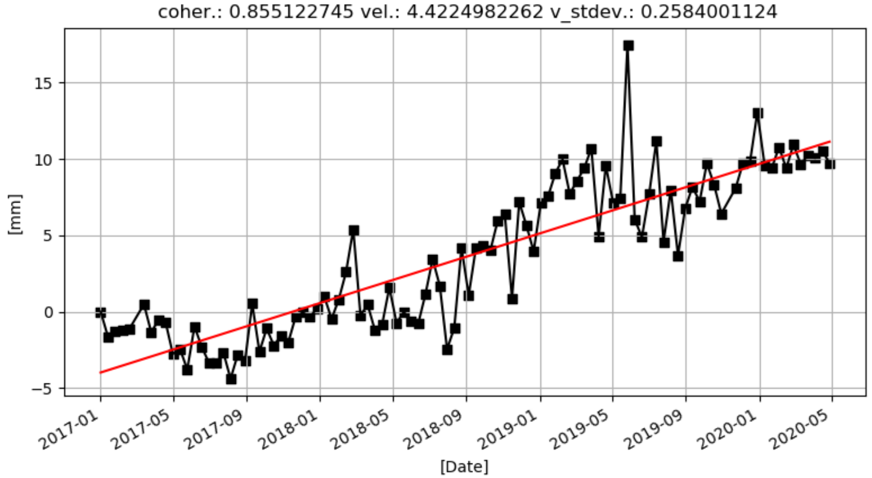
Ascending dataset velocity map and time-series of deformation estimated
Correlation between map and geological features



Viaduct S.Paolo in Catania

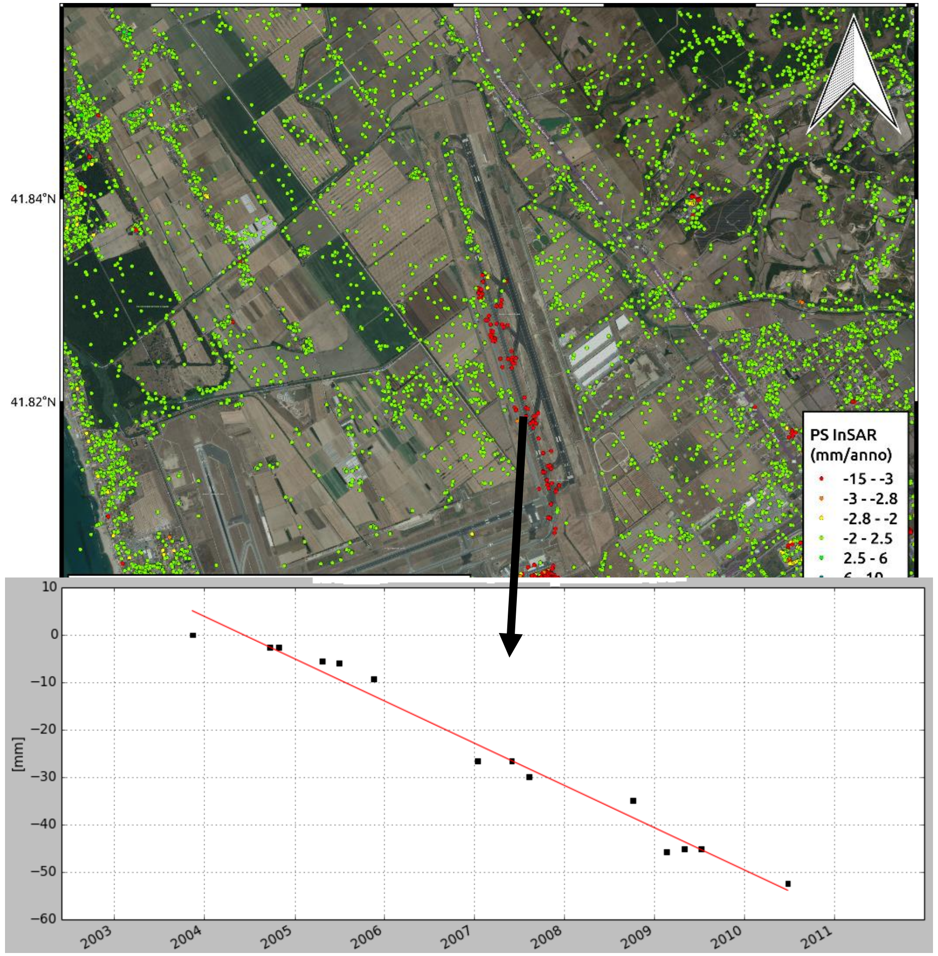
Example of deformation time-series: a diverging trend across the fault line is highlighted. Such movements are in agreement with the prevailing “tectonic regime” of the area bounding the E flank of Etna volcano

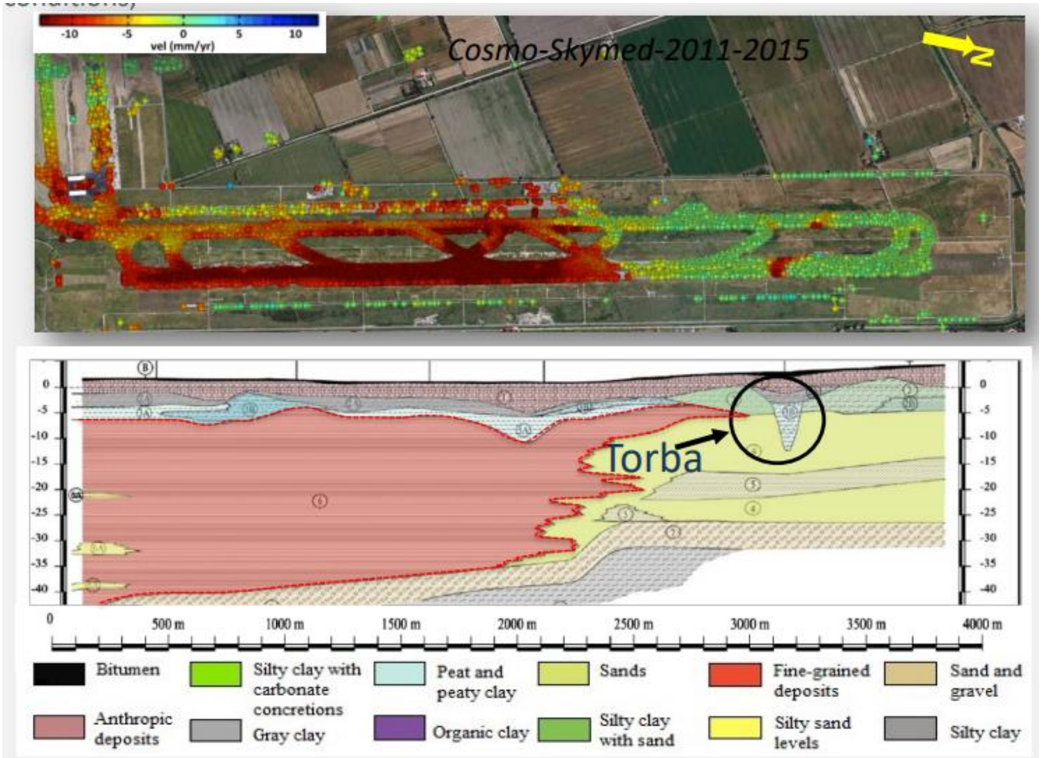




Infrastructures Monitoring: Leonardo da Vinci airport

MT-InSAR analysis has been applied to study some subsidence phenomena affecting the Leonardo da Vinci airport of Fiumicino (Rome)





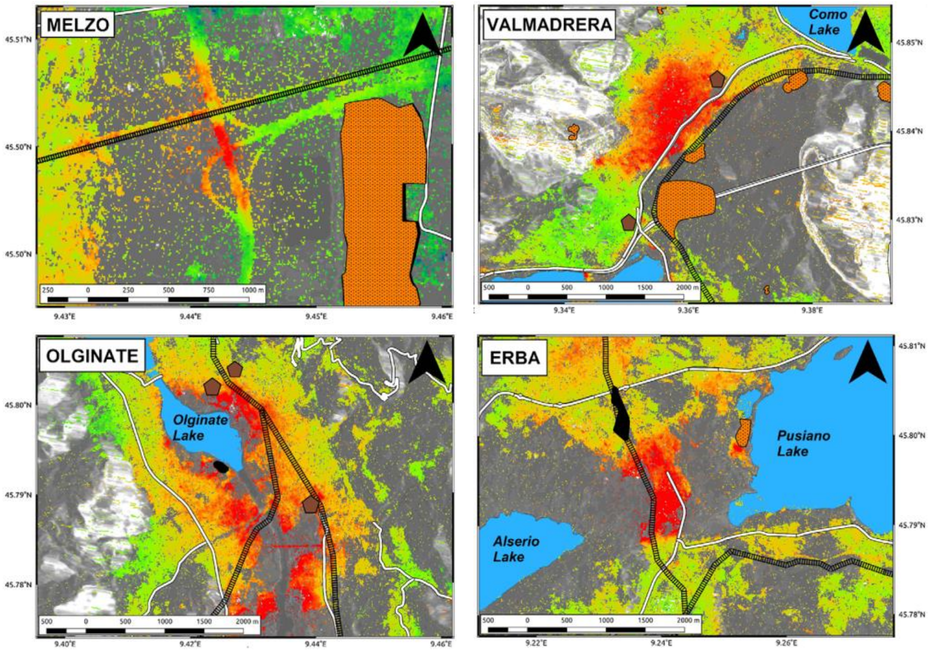
From Mazzanti et al., 2017 (https://www.asi.it/sites/default/files/attach/evento/06_mazzanti_workshop_asi_2017_c_2.pdf)

MT-InSAR analysis revealed a deformation gradient of about 5mm/yr along runway 3 of the Leonardo da Vinci Fiumicino airport. Such phenomenon of is due to the different type of sediments below the runway

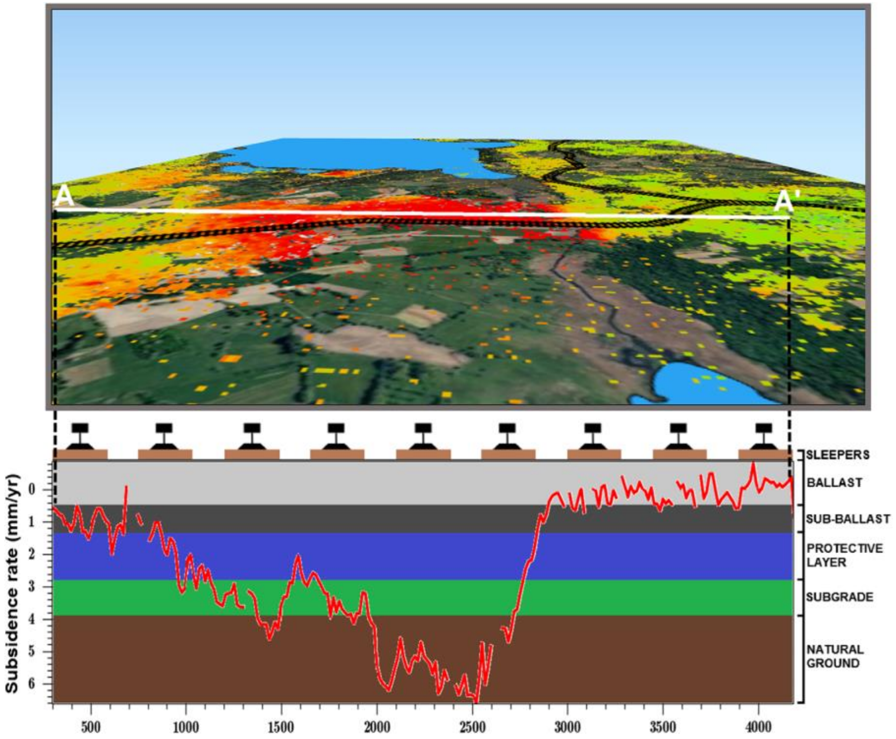
Infrastructures Monitoring: Lombardia railways lines

A dataset of high resolution Cosmo-SkyMed images acquired from 2014 to 2018 have been exploited to detect some anthropogenic-induced subsidence phenomena resting on several railways in Lombardia region, Northern Italy

MT-InSAR analysis allows detecting several phenomena peaking at about 7-8 mm/yr mostly induced by soil compaction effects, groundwater pumping and the presence of many quarries and landfills

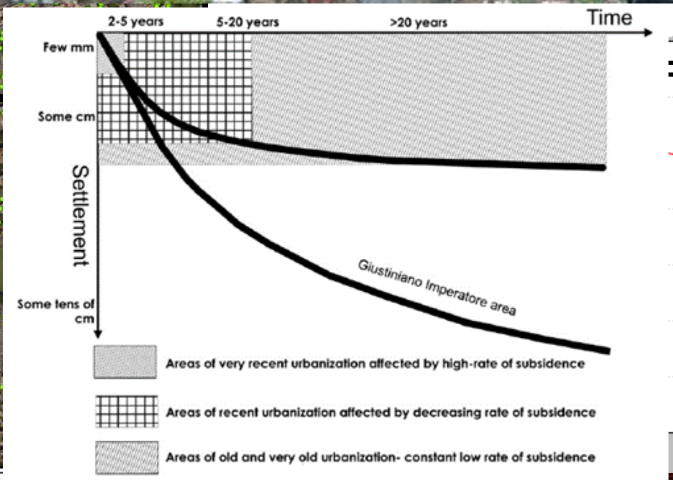


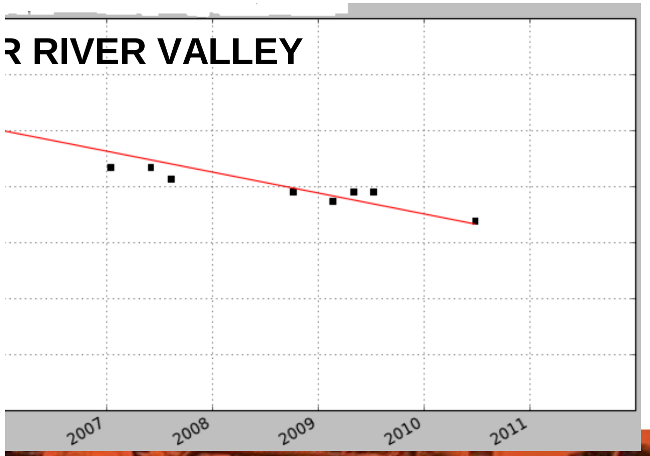
The subsidence induced by natural or anthropogenic reasons along a railway line produces a a load gradient in correspondence of the boundaries of the subsidence pattern, proportional to the difference in deformation rate between stable and subsiding areas.



Urban Area Monitoring - Rome city

MT-InSAR analysis can be used for monitoring urban area, allowing to evaluate any deformation phenomena that can damage urban planning or historical-cultural heritage





Conclusions

- Today new SAR missions ensure: worldwide coverage; dense temporal sampling; high resolution; stable orbital path; free available data.
- MT-InSAR is an effective tool for Earth Sciences and monitoring the effects of anthropogenic activities
- Natural (earthquakes, volcanoes, landslides, etc.) and Human induced hazards benefit from MT-InSAR analysis
- Multisource data integration is the key to unlock knowledge of deformation processes and their modelling
- Toward denser satellite constellation and geosyncronous missions